

Range of competitiveness of road FEV: mobility of passengers and freight transport analysis, performances and possible solutions

*Original*

Range of competitiveness of road FEV: mobility of passengers and freight transport analysis, performances and possible solutions / DALLA CHIARA, Bruno. - ELETTRONICO. - (2013), pp. 1-47. (Intervento presentato al convegno Green Cars, ITN 2013 tenutosi a Torino nel 26-27 September 2013).

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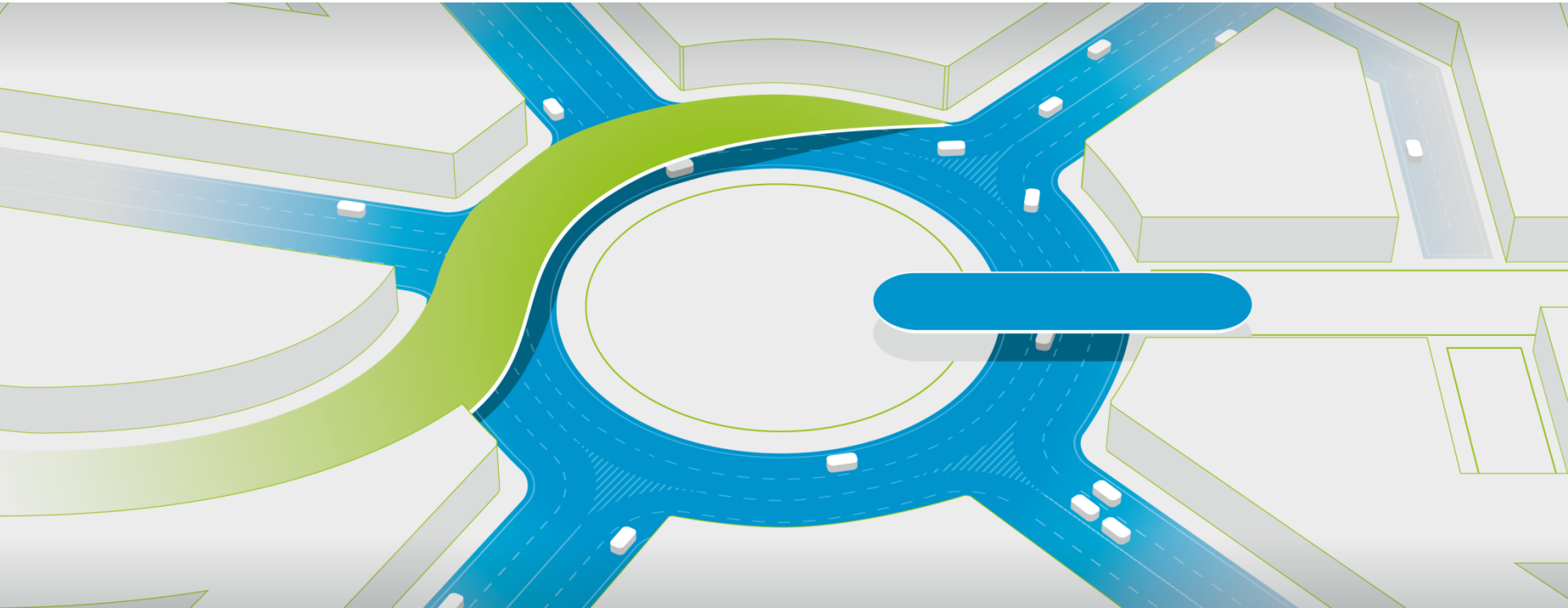
## Session

The development of electric mobility in Italy: plan and government incentives, the most advanced experiences and new trends in supply

Range of competitiveness of road FEV :  
mobility of passengers and freight transport analysis,  
performances and possible solutions

*Ambito di competitività dei veicoli elettrici su strada: analisi di mobilità di persone e del trasporto merci, prestazioni e possibili soluzioni.*

Torino - I, Thursday - 26<sup>th</sup> of September 2013, p.m.



eCo-FEV

Sept. 2012- May 2015

*EcO-FEV EU project working group, Politecnico di Torino*  
Torino - I , Lingotto, 26<sup>th</sup> of Sept. 2013

*Presented by:*  
*prof. Bruno DALLA CHIARA, Transport Engineering*  
*(Politecnico di Torino)*

This project is co-funded  
by the European Union



# Aims

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1. Analysis of **typical travels of vehicles** (passengers/freight), on the basis of the international mobility beside specific national or local
2. Area of **competitiveness of FEV** on the base of the analysis of demand
3. Performances and limitations on the supply side: **autonomy, batteries, power, performances, consumptions**
4. **Recharging possibilities** most suitable on the bases of the previous items
5. Consequent choices, with examples of di UC (use case) of the EcOFEV
6. Possible technical solutions.

# Premise: why?

Some figures, at European level (EU White Book on transports of 2001 [COM/2001/0370 def.]) estimated dependence on black oil at the 98%; in the USA it was estimated at 96% in the same period, reduced to **93.2% in 2010** [US Transportation Energy Data Book 2011, Ed30]). The White book on Transport Systems of 2011 reports a figure of **96% in EU**.

**Demand of motorised mobility** is nearly constant the last 2-3 years, but expressed in different ways in the last decades (urban contexts)

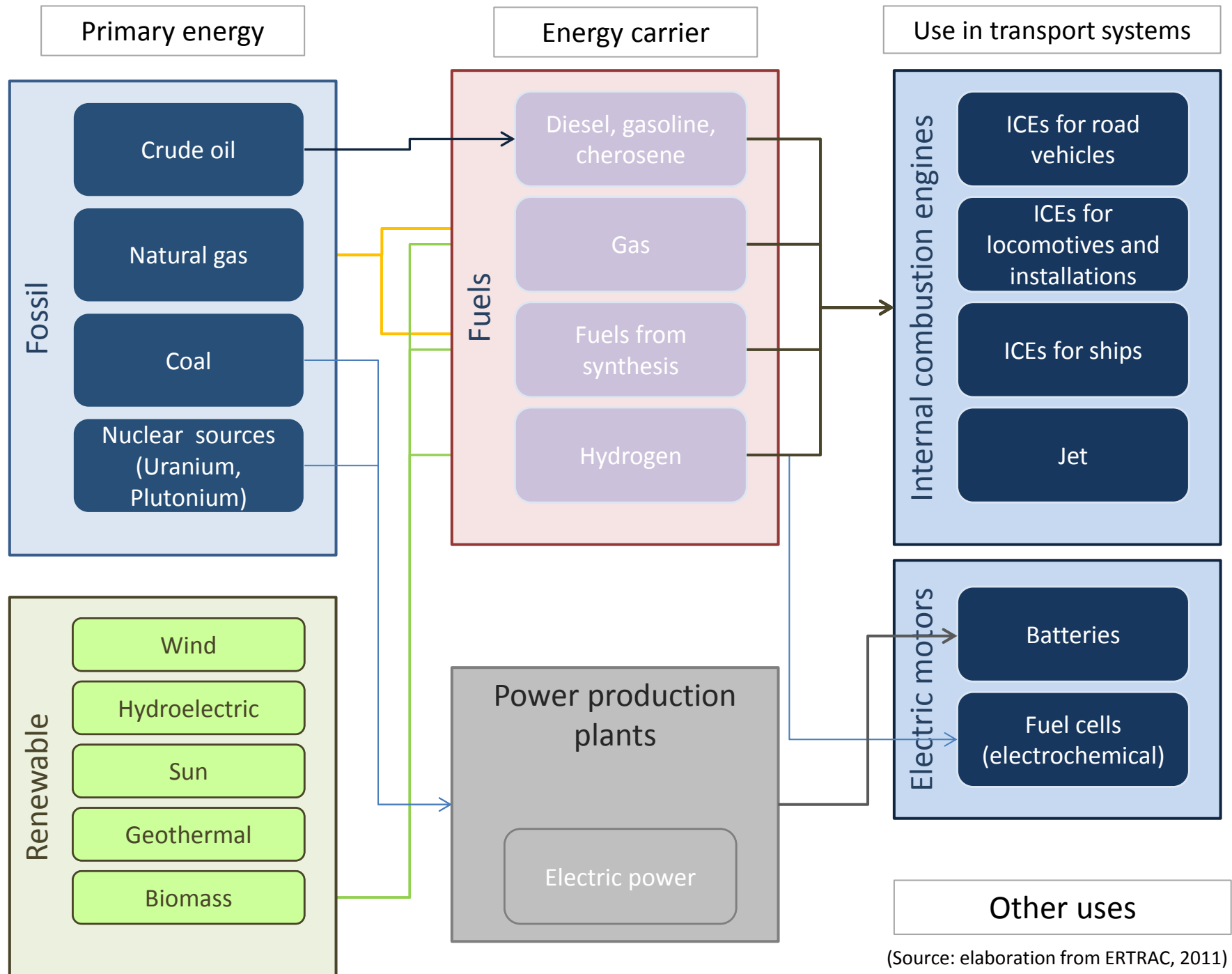
*The electrification of road transport is considered a key element in EU and worldwide for reducing the **near-monopoly of black oil** in this field and, consequently, local greenhouse gas (GHG) emissions generated by internal combustion engines, largely used at present for the whole travels.*

## WHITE PAPER

### Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system

Brussels, 28.3.2011 - COM(2011) 144 final

*“17. The challenge is to break the transport system’s dependence on oil without sacrificing its efficiency and compromising mobility.”*



(Source: elaboration from ERTRAC, 2011)

Analysis of typical travels of vehicles  
(passengers/freight), on the basis of the international  
mobility beside specific national or local



# Average distances covered in Italy

Starting from different samples, the following studies individuate comparable results:

| AVERAGE DAILY VEHICLE DISTANCE<br>[km] |      |
|--|------|
| ISFORT                                 | 35,1 |
| Polito <sup>(1)</sup>                  | 34,8 |
| «5T» (Turin ITS centre)                | 32,1 |
| CNIT/MIT 2004 <sup>(2)</sup>           | 33,8 |
| Polimi <sup>(3)</sup>                  | 38,7 |

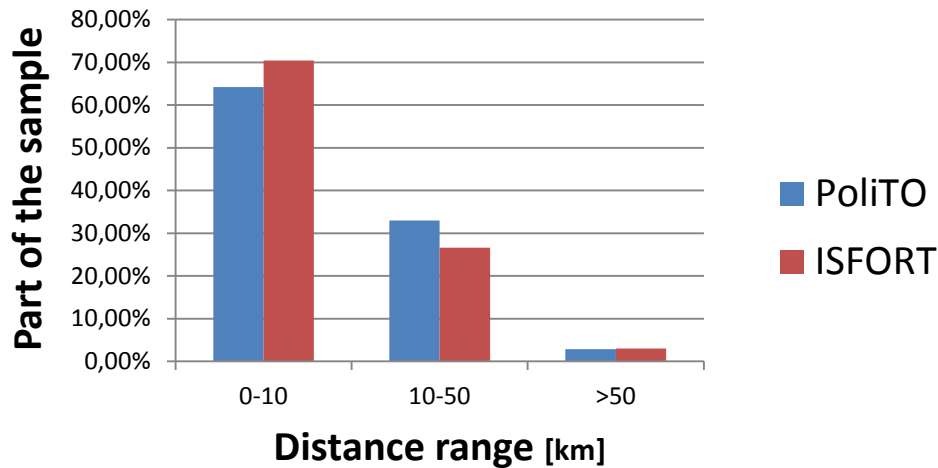
| AVERAGE VEHICLE TRIP<br>LENGTH [km] |       |                |
|-------------------------------------|-------|----------------|
|                                     | URBAN | EXTRA<br>URBAN |
| ISFORT                              | 4,7   | 25             |
| Polito <sup>(1)</sup>               | 6,2   | 14,4           |
| 5T                                  | 4,6   | 11,9           |

Sources:

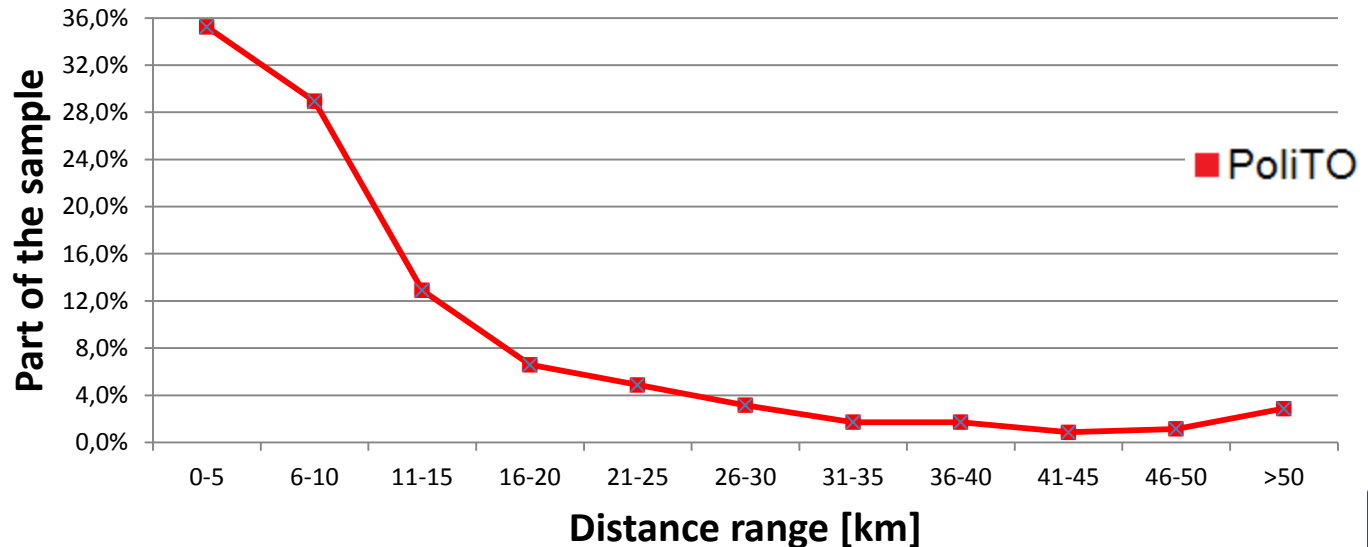
- (1) POLITECNICO DI TORINO, Dept. DIATI-Transport. Eng., *Indagine su mezzi di trasporto e mobilità motorizzata per il personale del Politecnico di Torino*, Risultati salienti, 2013
- (2) MINISTERO DELLE INFRASTRUTTURE E DEI TRASPORTI, *Conto nazionale delle infrastrutture e dei trasporti*, 2004
- (3) S. CASERINI, C. PASTORELLO, P. GAIFAMI, L. NTZIACHRISTOS, *Impact of the dropping activity with vehicle age on air pollutant emissions*, 2013

# Distribution of daily travels (working days)

## Average vehicle trip length distribution

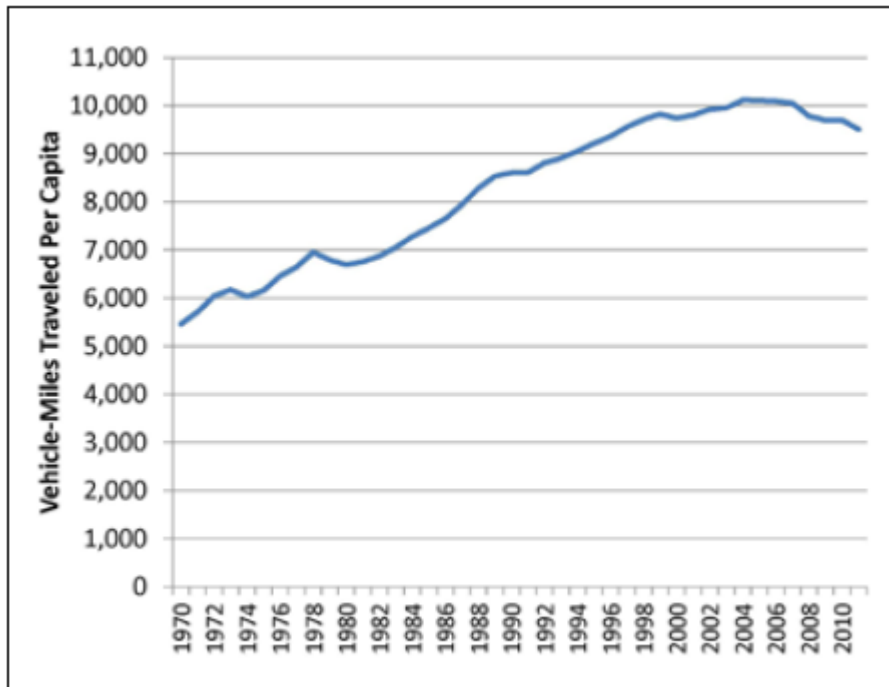


## Average vehicle trip length distribution



# Comparison between Italy and USA trends

After a period of continuous growth of the road transports, a period of stabilisation or inflection of the demand is showed also in the USA



Source: FRONTIER GROUP and U.S. PIRG EDUCATION FUND, Transportation and the new generation – Why young people are driving less and what it means for transportation policy, 2012

Average daily vehicle distances are higher than Italian and generally European ones, on values next to 30 miles (about 48 km)

|      | Number of daily vehicle trips (per driver) | Average vehicle trip length (miles) | Daily vehicle miles of travel (per driver) |
|------|--|-------------------------------------|--|
| 1990 | 3.3  | 8.9                                 | 28.5                                       |
| 1995 | 3.6  | 9.1                                 | 32.1                                       |
| 2001 | 3.4  | 9.9                                 | 32.7                                       |
| 2009 | 3.0  | 9.7                                 | 29.0                                       |

Source: S.C. DAVIS, S.W. DIEGEL, R.G. BOUNDY, *Transportation Energy Data Book: edition 31*, 2012

# Freight transport in Italy

| AVERAGE DAILY DISTANCES [km]                 |             |          |        |
|--|-------------|----------|--------|
|  | OWN ACCOUNT | FOR HIRE | GLOBAL |
| <b>CONFETRA<sup>(1)</sup></b>                | 48,8        | 165,1    | 118,6  |
| <b>Ministero dell'Ambiente<sup>(2)</sup></b> | 36,6        | 133,2    | 102,5  |
| <b>Autostrade per l'Italia<sup>(3)</sup></b> | -           | -        | 100,6  |

Data from “Autostrade per l'Italia” indicate that almost half of the heavy vehicles (48%) covers a distance less than 50 km

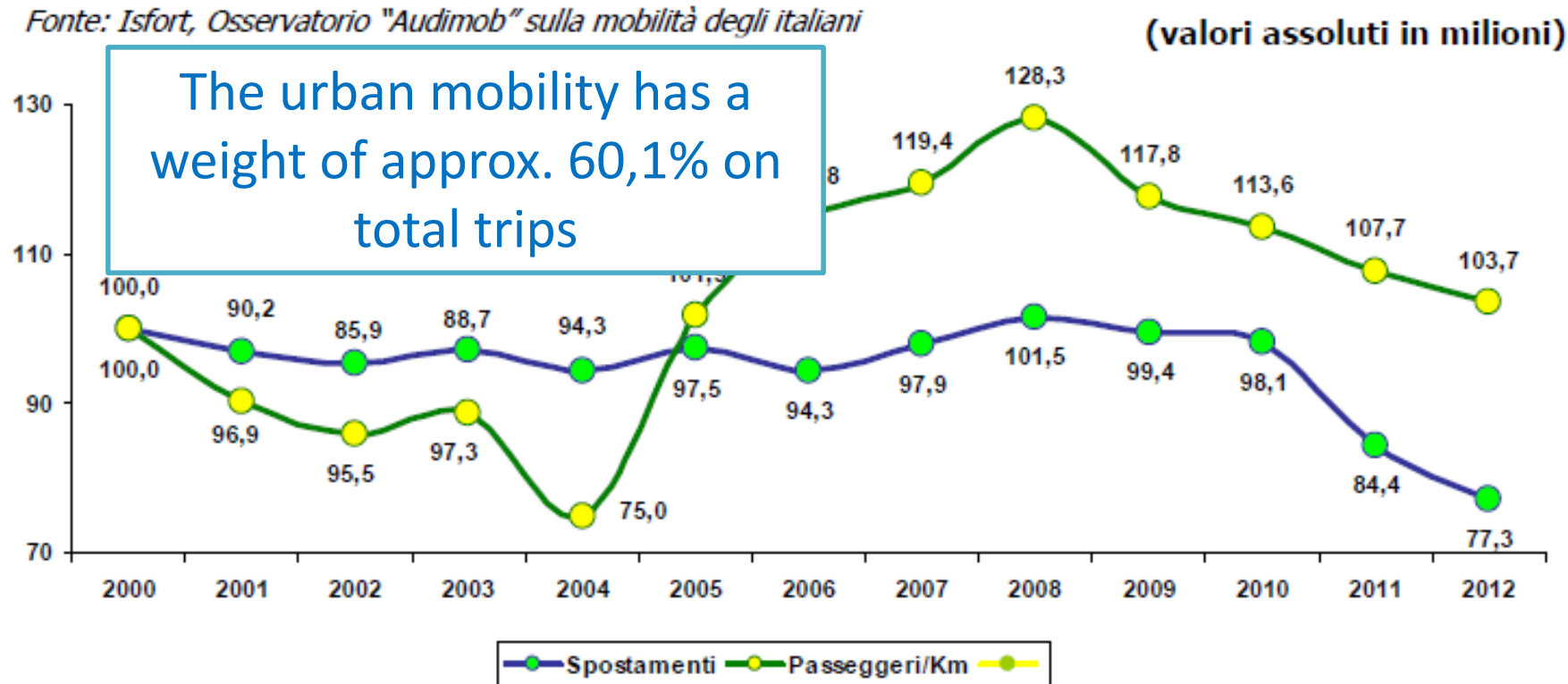
Sources:

- (1) CONFETRA, *Trasporti interni ed internazionali per titolo di trasporto e classe di percorrenza*, 2003
- (2) MINISTERO DELL'AMBIENTE E DELLA TUTELA DEL TERRITORIO E DEL MARE, *Il trasferimento modale sui grandi assi di scorrimento*, 2013
- (3) Autostrade per l'Italia, *Il traffico sulla rete del gruppo autostrade, valori a consuntivo*, 2012

# Mobility demand trend in Italy (2000-2012)

|  | 2012    | 2011    | 2010    | 2009    | 2008    | 2007   | 2000   |
|--|---------|---------|---------|---------|---------|--------|--------|
| Spostamenti <b>totali</b> in un giorno medio feriale   | 97,5    | 106,6   | 123,8   | 125,4   | 128,1   | 123,5  | 126,2  |
| Passeggeri*km <b>totali</b> in un giorno medio feriale | 1.261,2 | 1.302,2 | 1.381,4 | 1.432,8 | 1.561,0 | 1452,0 | 1216,2 |

Fonte: Isfort, Osservatorio "Audimob" sulla mobilità degli italiani



Fonte: Isfort, Osservatorio "Audimob" sulla mobilità degli italiani

# Motorized mobility in Italy

## Trips distribution for motorized vehicles in URBAN mobility (% values)

|                           | 2012        | 2011        | 2010      | 2007      |
|---------------------------|-------------|-------------|-----------|-----------|
| <b>Public transport</b>   | 15,1        | 13,5        | 12,9      | 11,5      |
| <b>Car</b>                | <b>79,7</b> | <b>79,4</b> | <b>80</b> | <b>81</b> |
| <b>Motorcycle / moped</b> | 5,2         | 7,1         | 7         | 7,6       |

## Trips distribution for motorized vehicles in EXTRA-URBAN mobility (% values)

|                           | 2012        | 2011        | 2010        | 2007        |
|---------------------------|-------------|-------------|-------------|-------------|
| <b>Public transport</b>   | 13,0        | 14,8        | 13,9        | 12,6        |
| <b>Car</b>                | <b>84,7</b> | <b>83,0</b> | <b>83,0</b> | <b>83,9</b> |
| <b>Motorcycle / moped</b> | 2,2         | 2,2         | 3,1         | 3,4         |

Source: ISFORT, ANAV, ASSTRA, *Una leva per la ripresa – 10° rapporto sulla mobilità in Italia*, 2013

- Area of competitiveness of FEV on the base of the analysis of demand
- Performances and limitations on the supply side: autonomy, batteries, power, performances, consumptions
- Recharging possibilities most suitable on the bases of the previous items

Private transport

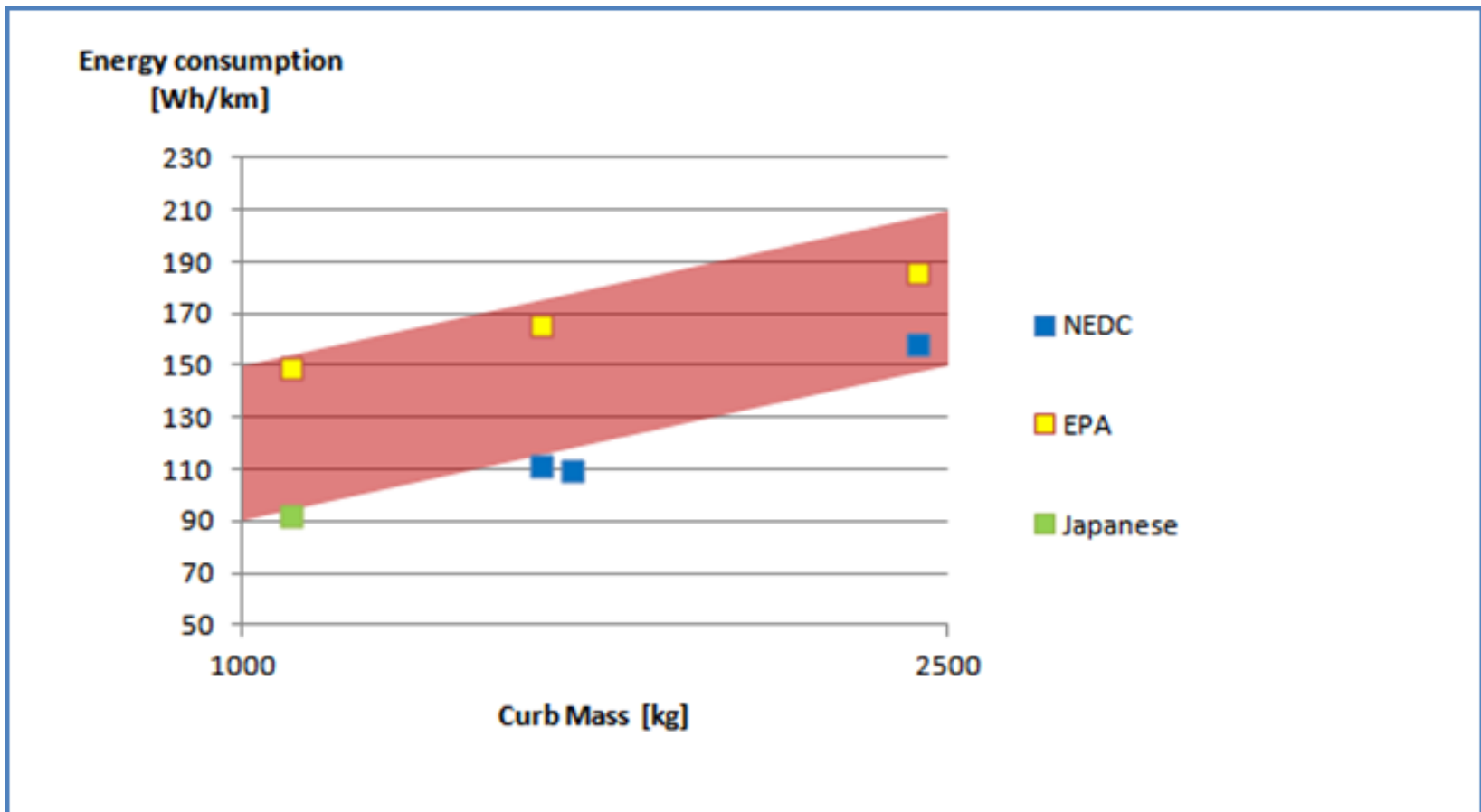
Freight transport

Public transport and multimodal mobility

- Area of competitiveness of FEV on the base of the analysis of demand
- Performances and limitations on the supply side: autonomy, batteries, power, performances, consumptions
- Recharging possibilities most suitable on the bases of the previous items

## Private transport





Full electric cars energy consumption range according to three driving cycles  
[elabor. by Politecnico di Torino, Filidoro, 2013]

|                |                            | Maximum driving range [km] given the charging speed specified in the line below |   |
|----------------|----------------------------|---|---|
| Curb mass [kg] | Energy consumption [Wh/km] | Slow charging: 220 V, 16 A, maximum power≈3.5 kW                                | Mode 2 charging: 220 V, 30 A, maximum power≈7kW |
| 1000           | 150                        | 187   | 373   |
| 1500           | 170                        | 165   | 329   |
| 2000           | 190                        | 147   | 295   |
| 2500           | 210                        | 133   | 267   |

Maximum obtainable driving range, **eight-hour charging**  
[elabor. by Politecnico di Torino, Filidoro, 2013]

The calculation does not take into account the limits caused by the batteries admissible size though. The two types of charging methods would need respectively a 30 kWh and a 60 kWh battery pack. Recalling the Li-ion batteries characteristics, that would correspond to 200÷300 kg and 400÷600 kg respectively. Definitely it would not be possible to afford 500kg-heavy batteries in a vehicle with a total mass of 1000 kg. Small to medium electric cars are typically featured by a **20÷30 kWh battery pack**. As a consequence is possible to notice that the limit on the maximum driving range between charges is not imposed by the charging methods, even if fast charging is not considered, but from the size of the batteries.

Road tests performed by specialized magazines always show **real consumptions** to be higher than the one obtained through **standard driving cycles**, particularly NEDC.

There is no direct way of measuring the **State Of Charge** of a Li-Ion battery indeed. There are indirect ways of estimating it, but each suffers from limitations.

The electric cars designed in recent years show that is affordable to have approx. **up to 20% of the curb weight given by batteries**.

|                |                               | Driving range [km] given the charging speed<br>specified in the line below |      |   |  |
|----------------|-------------------------------|--|------|---|--|
| Curb mass [kg] | Energy consumption<br>[Wh/km] | 3.5 kW   | 7 kW | AC three-phase<br>charging: 400 V,<br>30 A, max.<br>power≈20 kW | DC fast<br>charging: 400<br>V, 125 A,<br>maximum<br>power≈50kW |
| 1000           | 150                           |  |      | 67  | 167  |
| 1500           | 170                           |  |      | 59  | 147  |
| 2000           | 190                           |  |      | 53  | 132  |
| 2500           | 210                           |  |      | 48  | 119  |

Obtainable driving range, **half-hour charging**  
[elabor. by Politecnico di Torino, Filidoro, 2013]

|                |                            | Charging time [min] given the charging speed specified in the line below |      |       |       |
|----------------|----------------------------|--|------|-------|-------|
| Curb mass [kg] | Energy consumption [Wh/km] | 3.5 kW   | 7 kW | 20 kW | 50 kW |
| 1000           | 150                        | 90   | 45   | 16    | 6     |
| 1500           | 170                        | 102  | 51   | 18    | 7     |
| 2000           | 190                        | 114  | 57   | 20    | 8     |
| 2500           | 210                        | 126  | 63   | 22    | 9     |

**Charging time** needed to obtain a **35 km driving range**

[elabor. by Politecnico di Torino, Filidoro, 2013]

# BATTERY RE-CHARGING

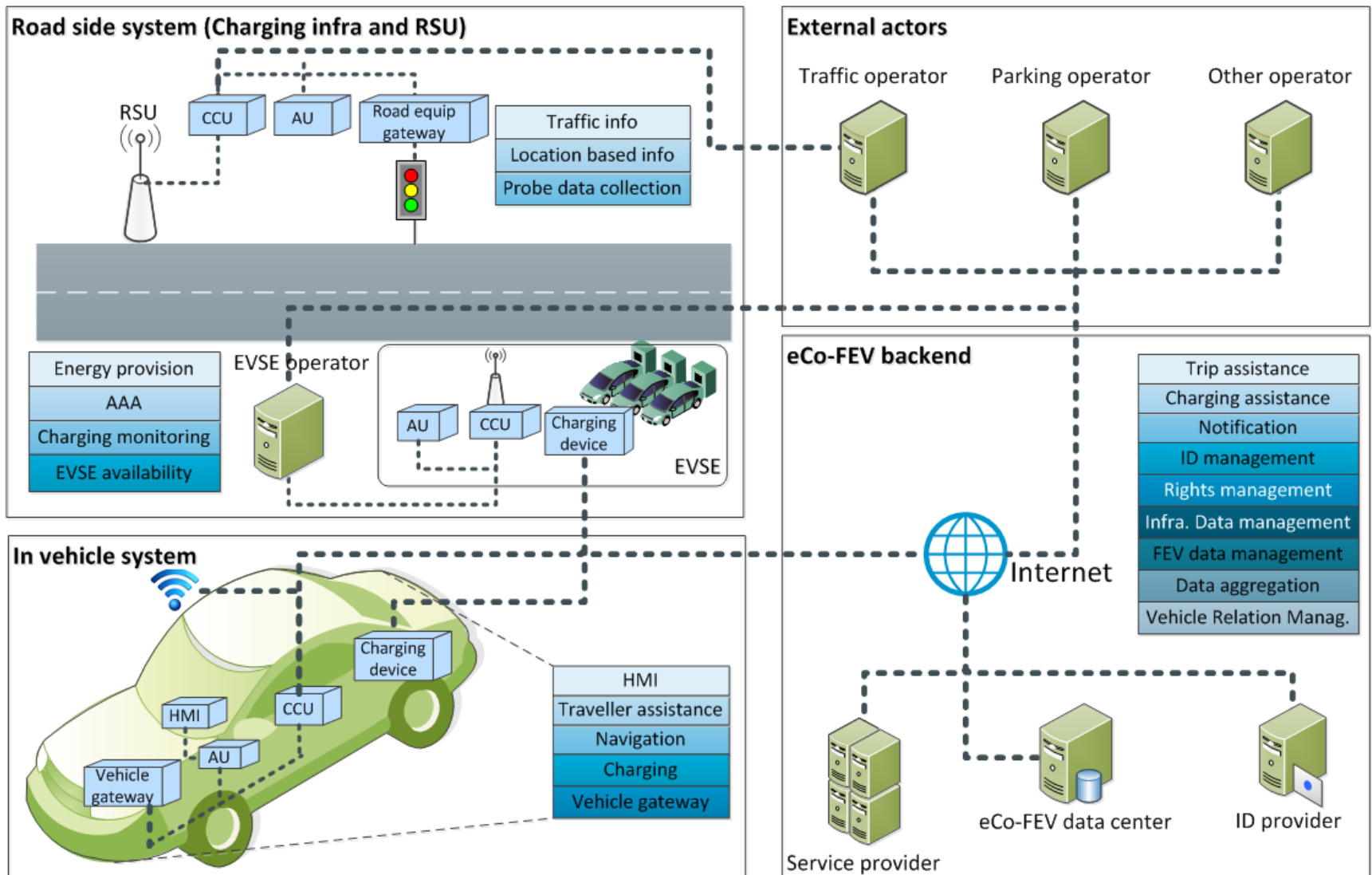
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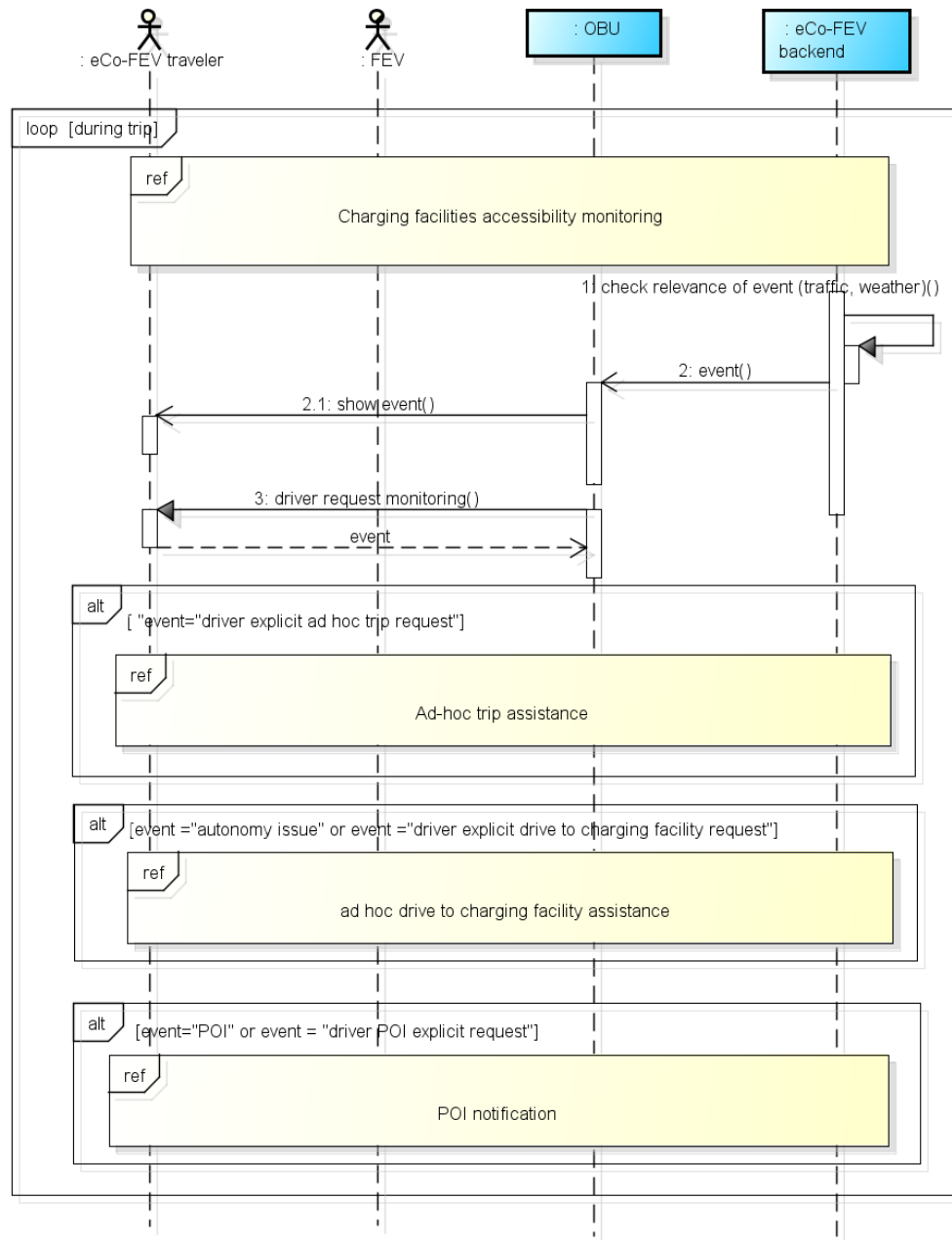
A. **Conductive** charging

B. **Inductive** contactless charging (contactless implicit)

both of them can be

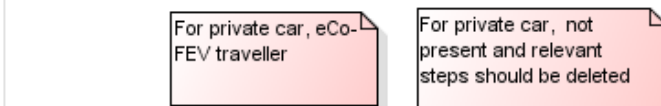
1. either **motionless** or **in motion** (e.g. inductive charging in motion);
2. either **driverless** or **while driving** (e.g. inductive charging while driving).







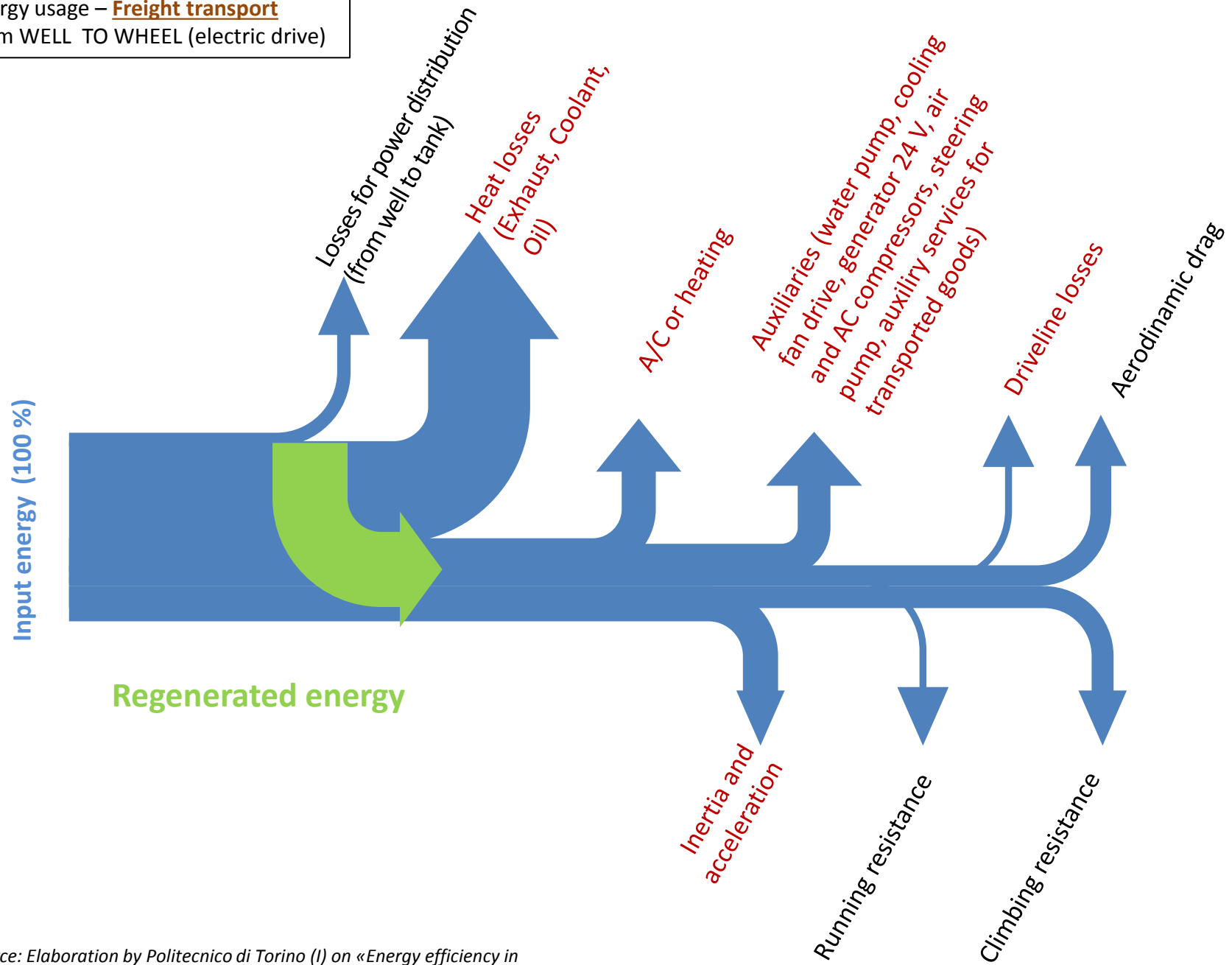
## ad CWD charging management



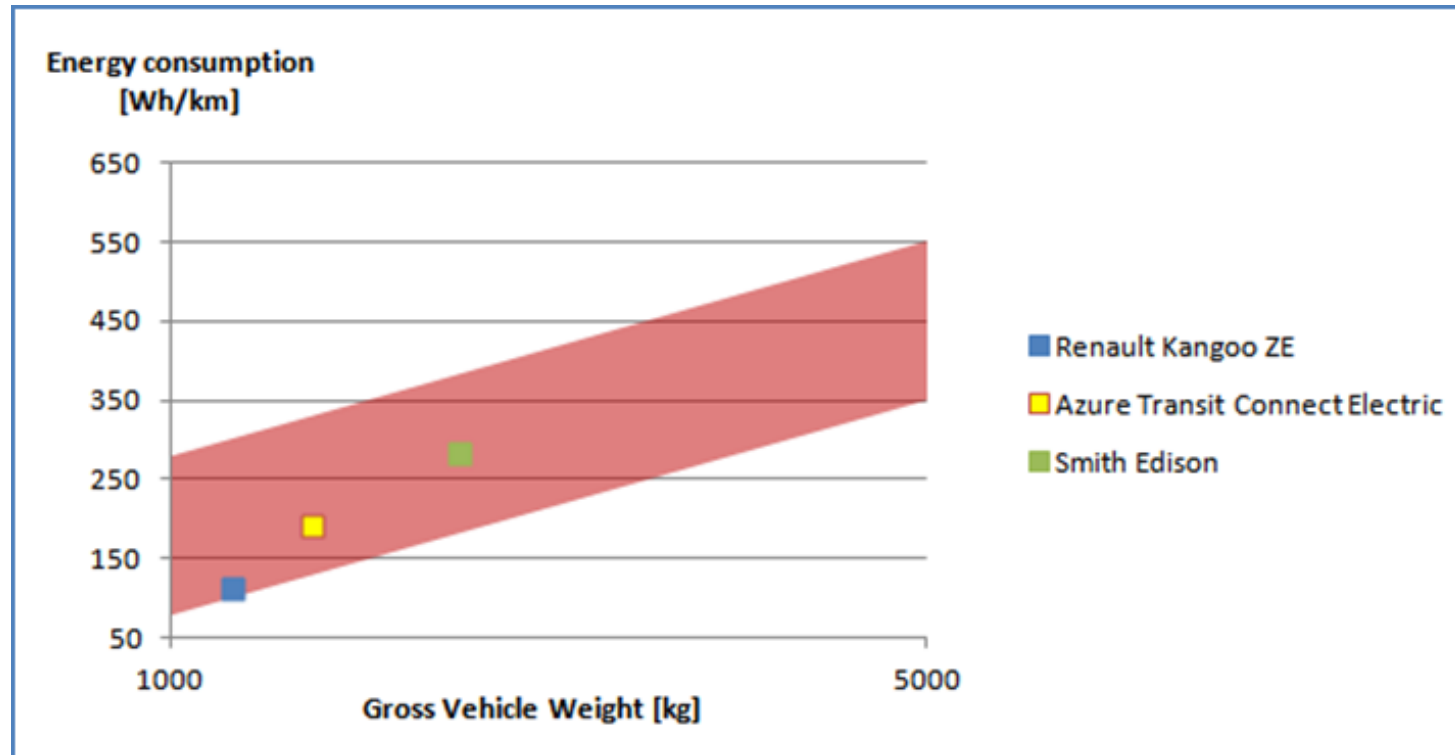
- Area of competitiveness of FEV on the base of the analysis of demand
- Performances and limitations on the supply side: autonomy, batteries, power, performances, consumptions
- Recharging possibilities most suitable on the bases of the previous items

## Freight transport

Energy usage – **Freight transport**  
From WELL TO WHEEL (electric drive)



Source: Elaboration by Politecnico di Torino (I) on «Energy efficiency in public transport systems: what is the next stop on the line»? (F. Burkhart), Public Transport International n° 5, Sep-Oct 2012



Full electric light commercial vehicles energy consumption estimation, with some examples

*Payload conditions!*

|                           |                            | Maximum driving range [km] obtainable through the charging speed in the line below |               |                |
|---------------------------|----------------------------|--|---------------|----------------|
| Gross Vehicle Weight [kg] | Energy consumption [Wh/km] | 3.5 kW charging  | 7 kW charging | 20 kW charging |
| 1300                      | 300                        | 93   | 187           | 533            |
| 2000                      | 350                        | 80   | 160           | 457            |
| 3500                      | 450                        | 62   | 124           | 356            |
| 5000                      | 550                        | 51   | 102           | 291            |

Maximum obtainable driving range, **eight-hour charging**

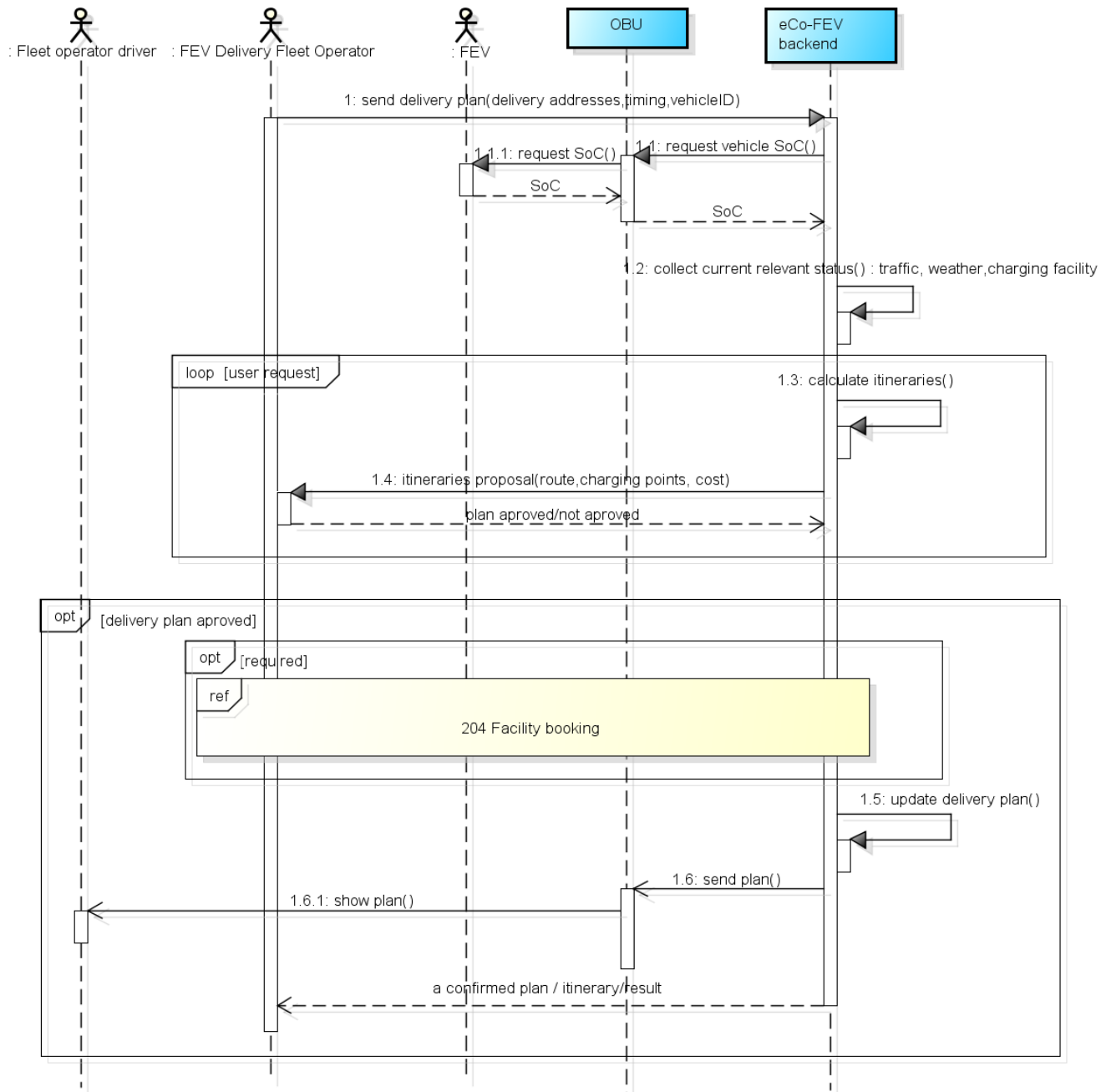
The calculation does not take into account again the limits caused by the batteries admissible size

Charging time [min] given the charging speed specified in the line below

| Gross Vehicle Weight [kg] | Energy consumption [Wh/km] | 3.5 kW | 7 kW | 20 kW | 50 kW |
|---------------------------|----------------------------|--------|------|-------|-------|
| 1300                      | 300                        | 180    | 90   | 32    | 13    |
| 2000                      | 350                        | 210    | 105  | 37    | 15    |
| 3500                      | 450                        | 270    | 135  | 47    | 19    |
| 5000                      | 550                        | 330    | 165  | 58    | 23    |

**Charging time** needed to obtain a 35 km driving range

The calculation does not take into account again the limits caused by the batteries admissible size



- Area of competitiveness of FEV on the base of the analysis of demand
- Performances and limitations on the supply side: autonomy, batteries, power, performances, consumptions
- Recharging possibilities most suitable on the bases of the previous items

## Public transport and multimodal mobility



### Main features:

- Fixed path
- Known distances
- Known and usually necessary stops
- Scheduling of activities (driver's rest) at terminals/depots

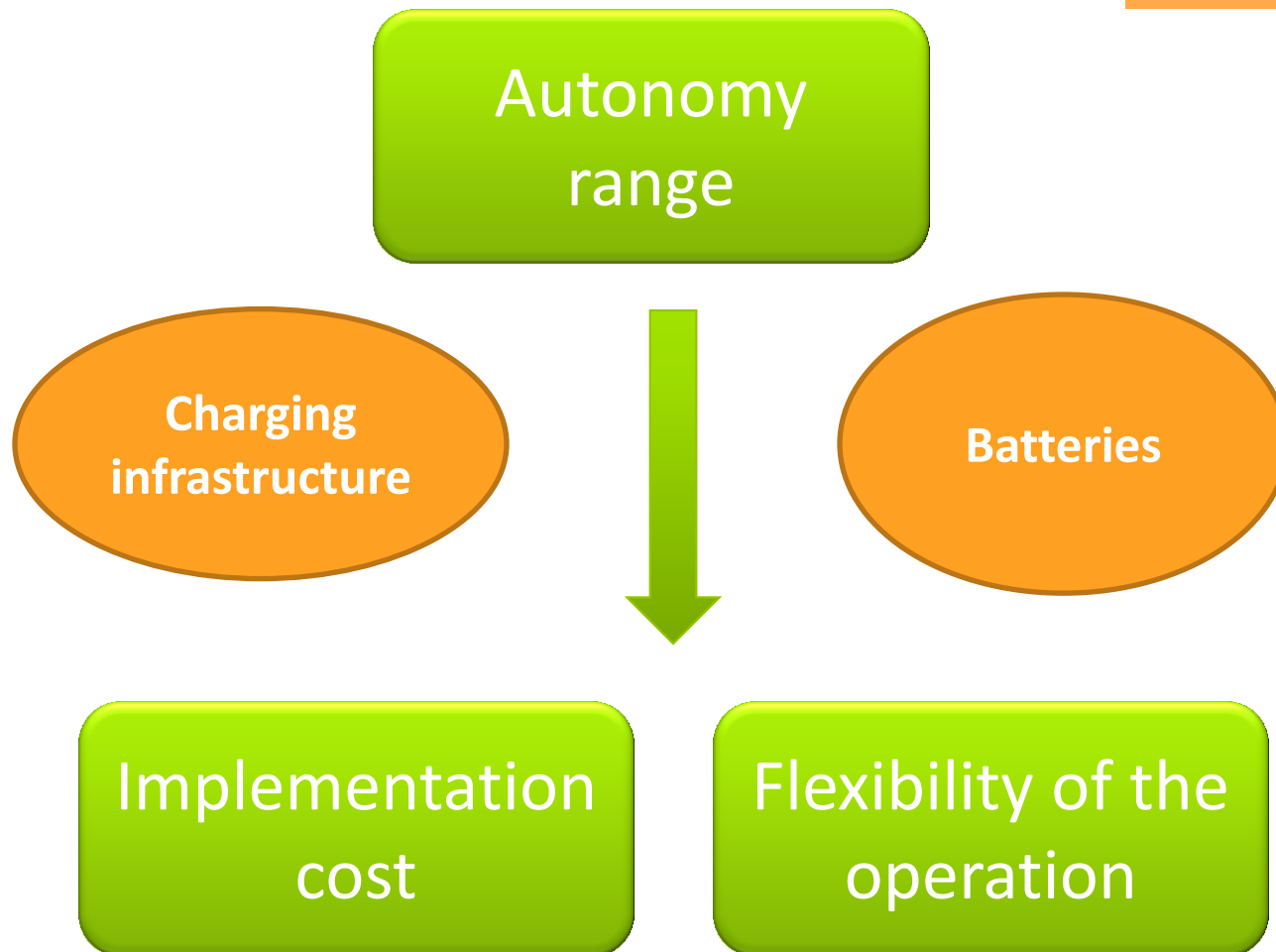
### Though:

- Variability of the mass
- Possible aging effects on batteries
- Transport for a public service (no risks, no nearly-empty SOC allowed)

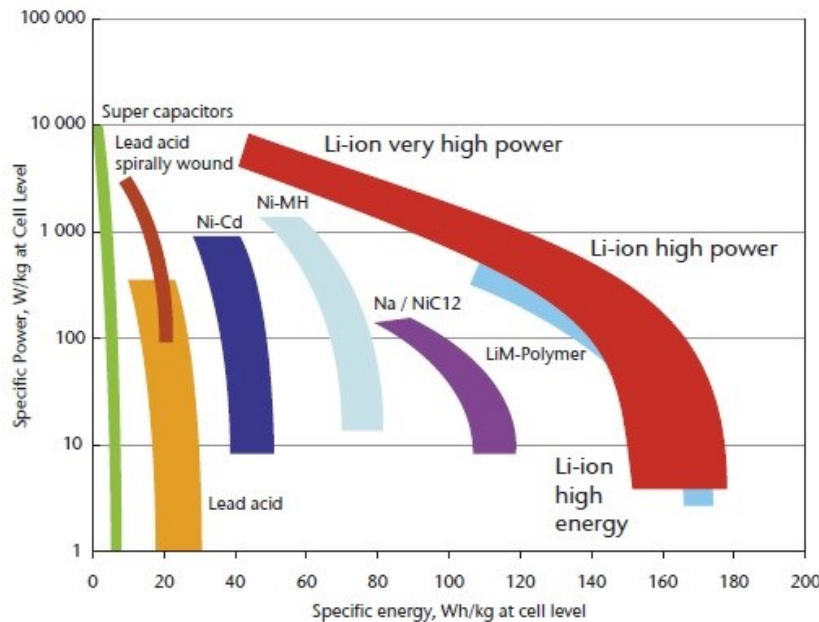
# Factors driving change towards electrification of public transport



# Factors limiting change towards electrification of public transport



# Electric energy storage element



Most used

- Li-iron phosphate
- Li-titanate
- Super capacitors

- Specific energy
- Cycle life
- Purchasing costs
- Opportunity charging



- Sizing of the storage element

# Electric bus typologies and energy consumption

**Trolley bus**  
(Non autonomous)

**Battery bus**  
(Autonomous, partially autonomous)

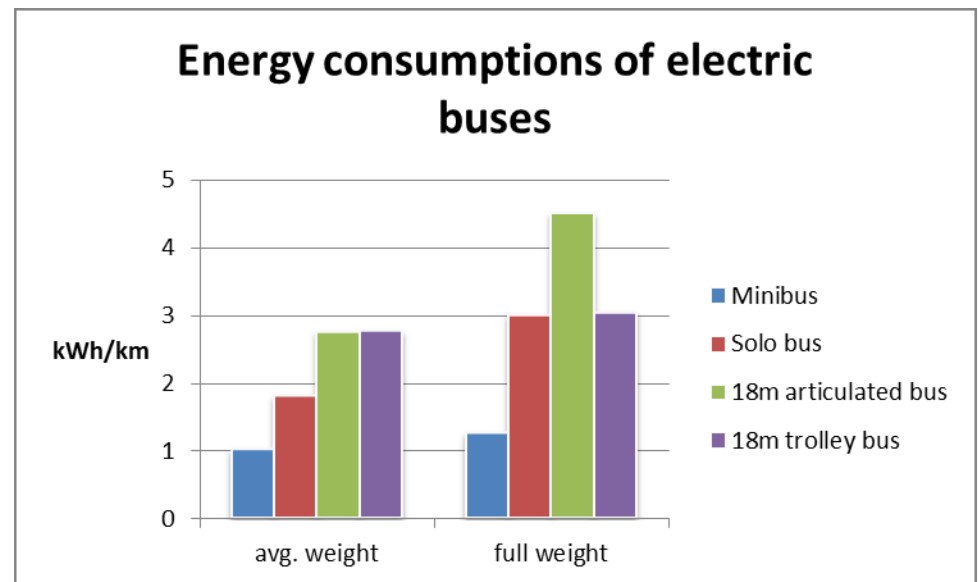
**Capabus**  
(Partially autonomous)

- Dimensions
  - Number of passengers
  - Avg. energy consumption
- Energy storage element
  - Autonomy range
  - Charging time
  - Purchasing cost
- Charging devices on board
  - Adaptation to infrastructure

# Electric bus typologies and energy consumption

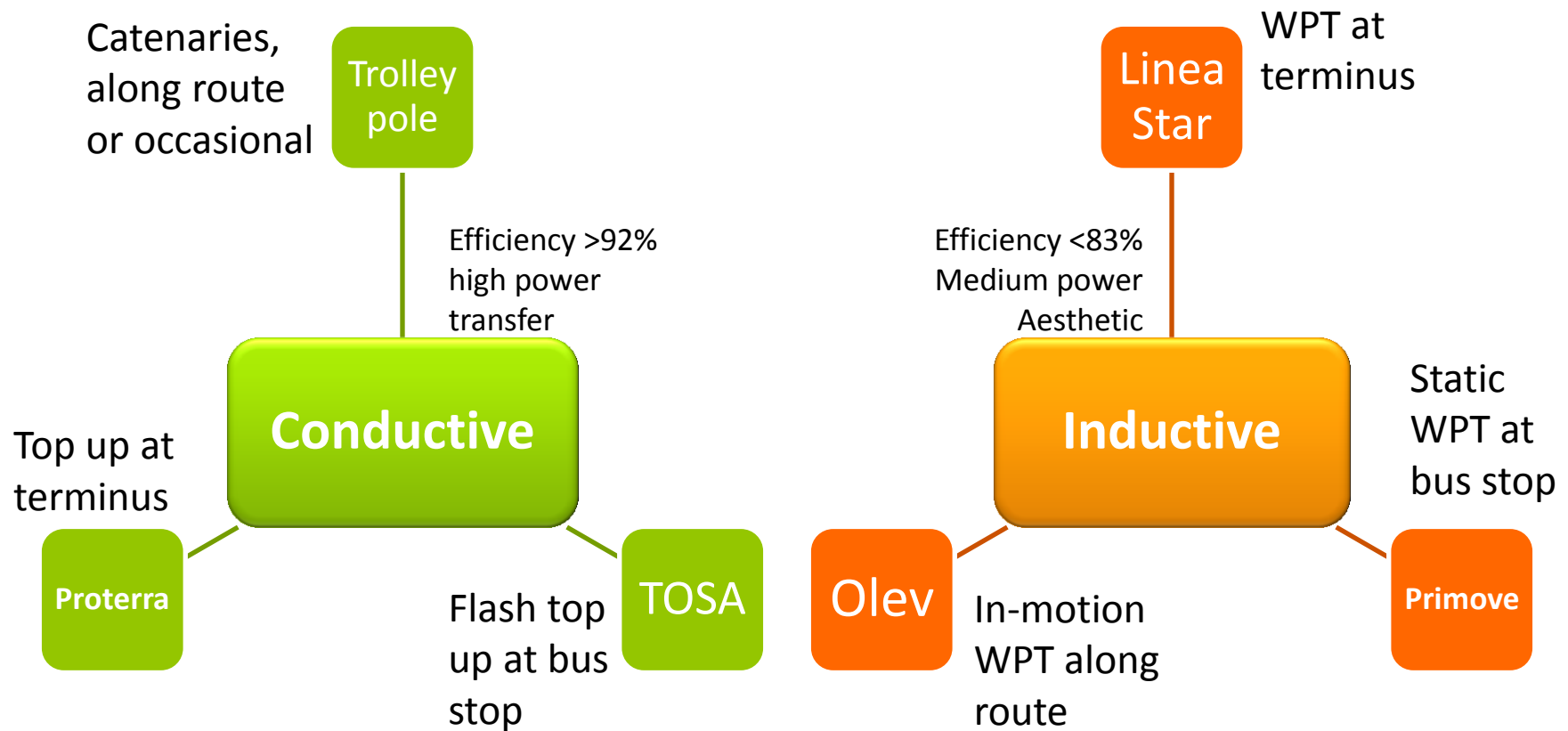
For given traffic and route, energy consumption is mainly influenced by :

- Vehicle mass
- Auxiliary devices



Exemplary consumption value: 1kWh/km

# Investigated charging technologies and infrastructure systems



# Linea Star study case: example

[source: some data were provided by GTT, Spring-Summer 2013]

## Current bus characteristics:

- 7.48m, 34 passengers
- 8750-11500 kg
- Pb-gel batteries, 60.4 kWh, 1790 kg
- Three phase asynchronous motor (max 120kW, 65kW)

## Route:

- Turin city center, 6km
- Total of 120km/day

## Inductive charging at terminus:

- Efficiency 70%
- Power transfer  $\leq 40\text{kW}$
- 10-15 minutes

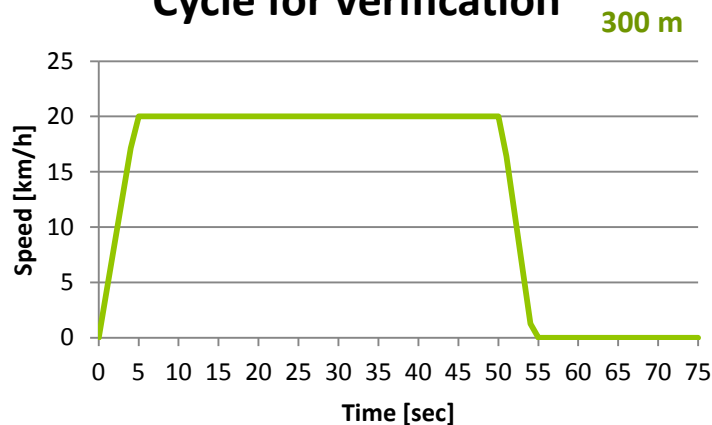




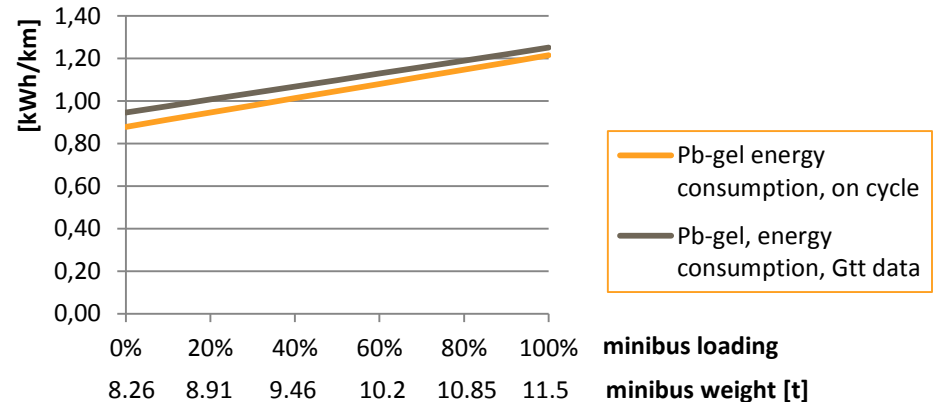
# Linea Star study case - current status

| Pb-gel batteries                    | Data given by GTT |
|-------------------------------------|-------------------|
| Full load energy consumption        | 1.25 kWh/km       |
| Weight effect on energy consumption | 0.094 kWh/km*ton  |

**Cycle for verification**

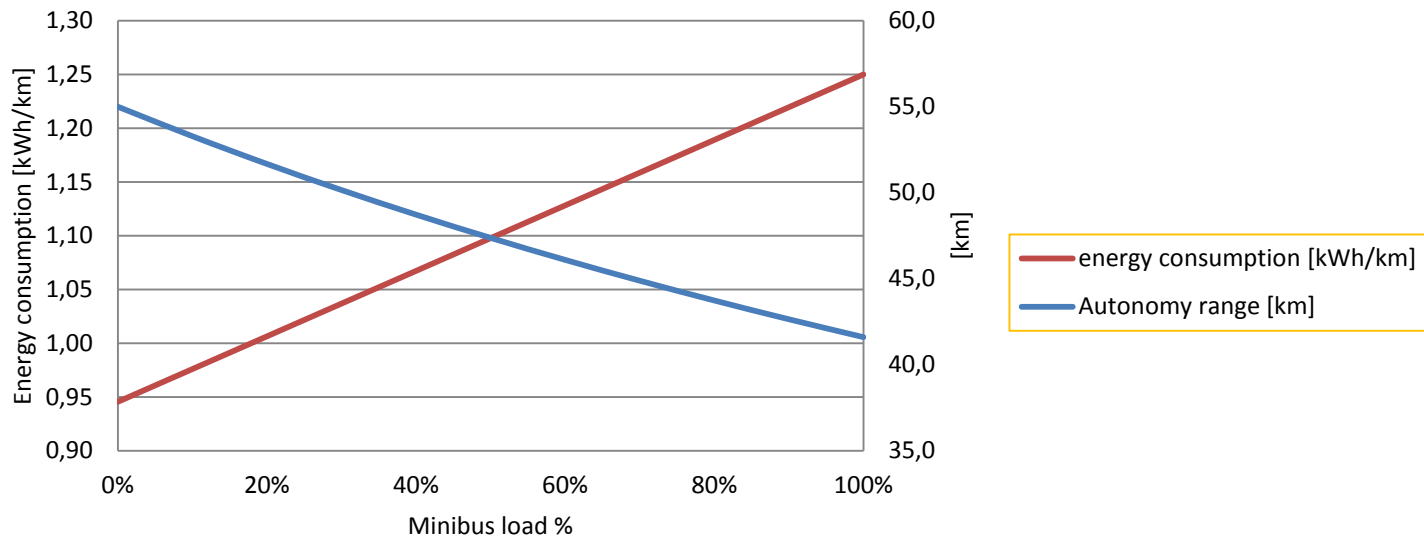


**Verification of energy consumption, Pb-gel**



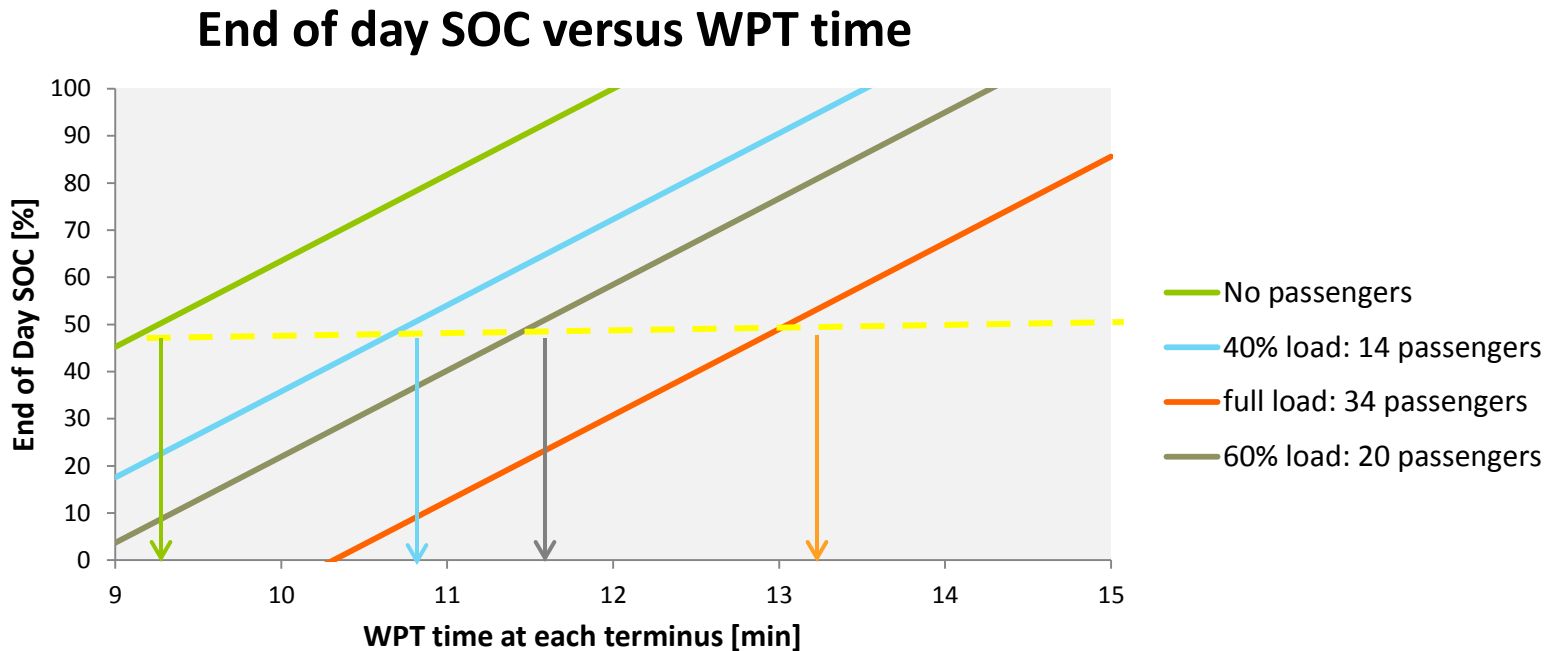
# Linea Star study case - current state

**Energy consumption and range autonomy, Pb-gel**



|             |               |          |             |       |
|-------------|---------------|----------|-------------|-------|
| 40% loading | 14 passengers | 9.56 ton | 1.07 kWh/km | 49 km |
| 60%         | 20 passengers | 10.2 ton | 1.13 kWh/km | 46 km |

# Linea Star study case - current state



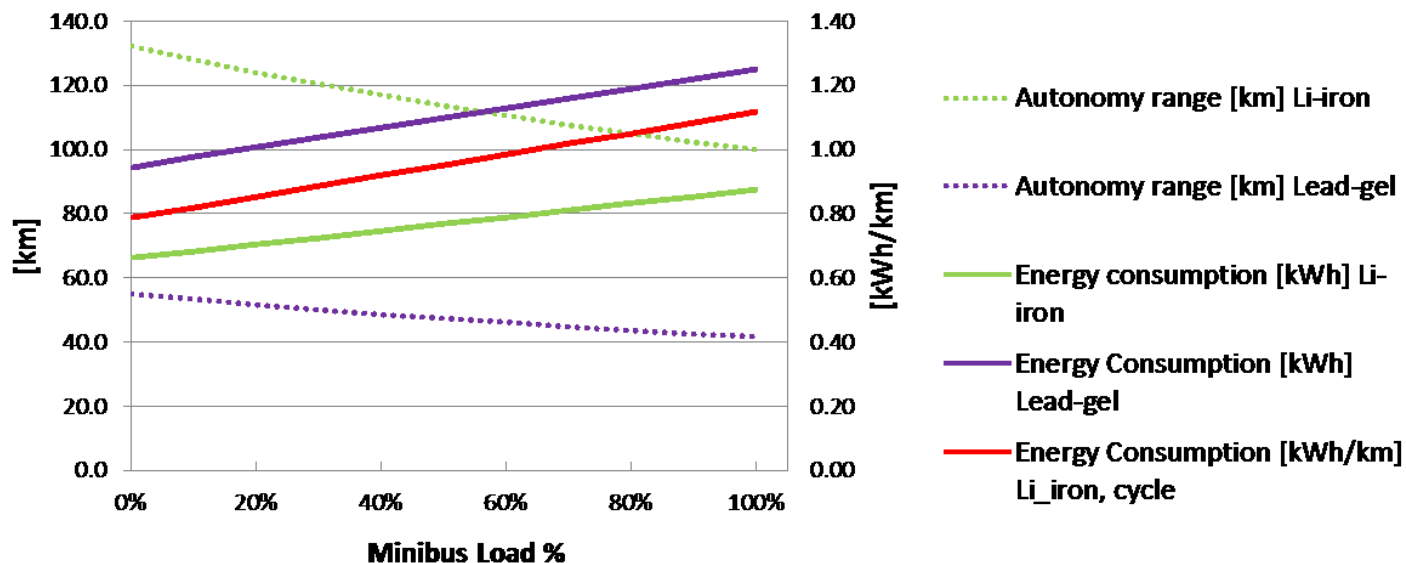
- Pb-gel useful SOC: 40-90 %

- 6km route
- 20 journeys
- 19 stops

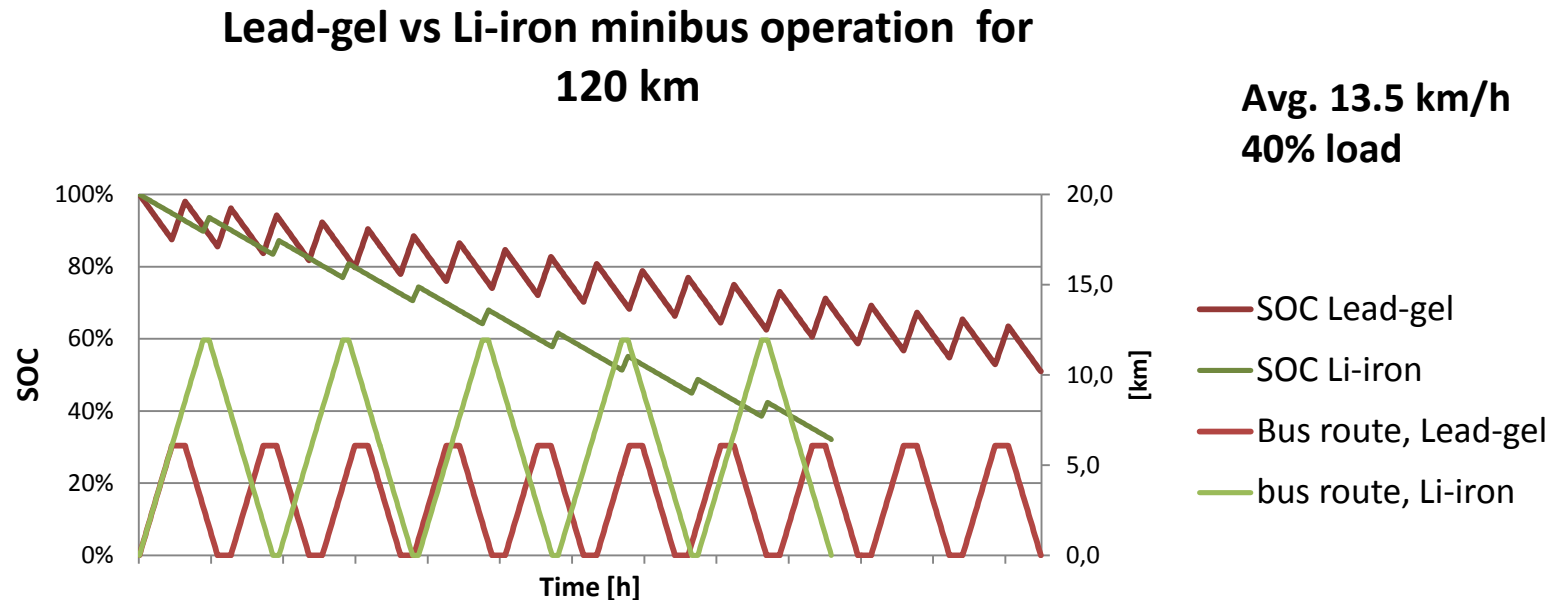
# Linea Star study case - Li-iron phosphate versus Pb-gel batteries

- Weight reduction (778 kg)
- Improvements in regenerative braking  -30% energy consumption

Energy consumption, range autonomy and data verification,  
Pb-gel versus Li-iron phosphate



# Linea Star study case - Li-iron phosphate versus Pb-gel batteries



- Lead-gel (9.56 ton, 1.07 kWh/km): 20 journeys of 6km each with 19 stops of 11' for inductive charging
- Li-iron ( 8.78 ton, 0.75 kWh/km): 10 journeys of 12km each with 9 stops of 5' for inductive charging

# sd Public transport monitoring

: eCo-  
back

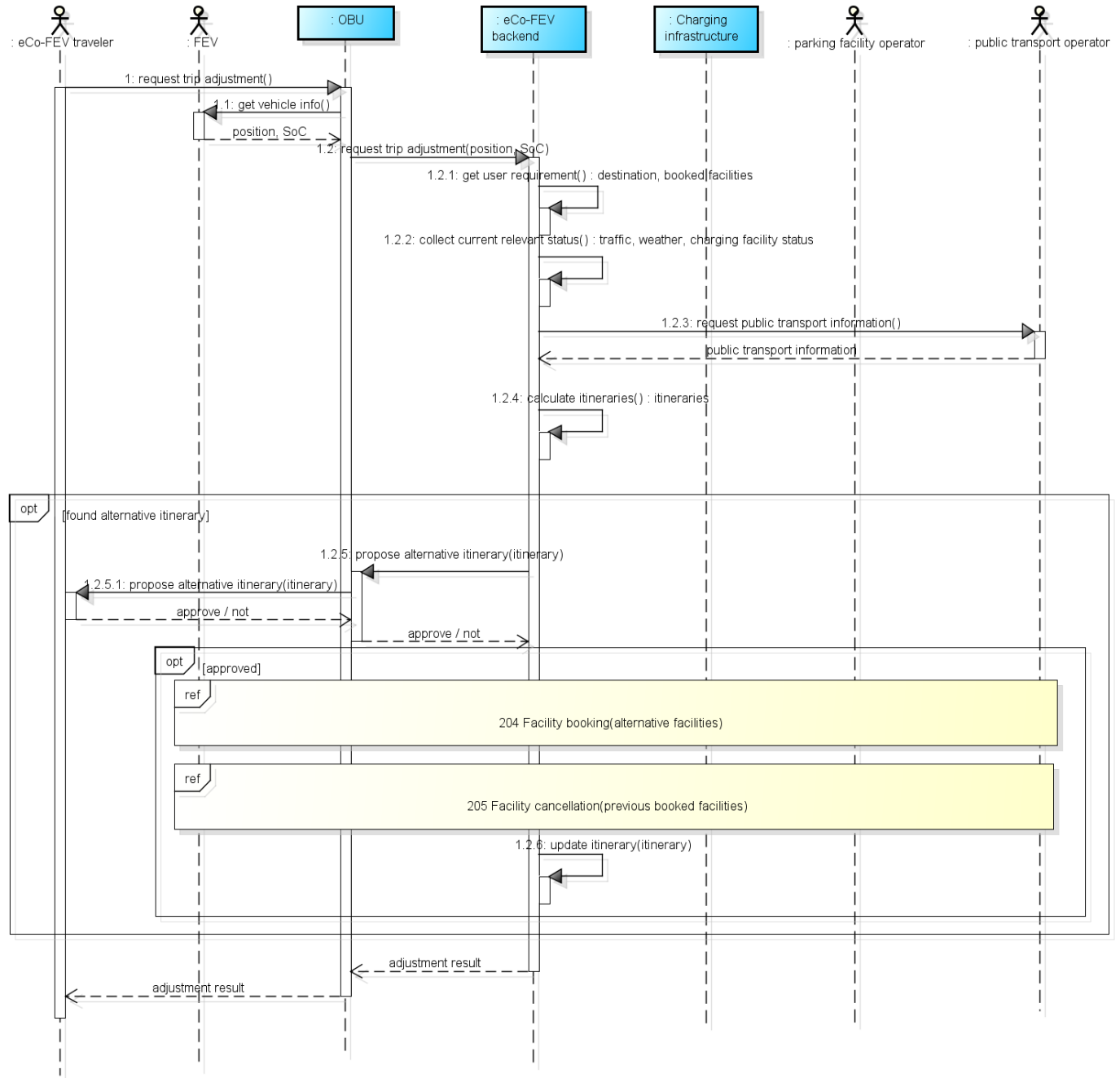
alt [Push]

loop [update cond

[Pull]

loop [backend req

## sd trip adjustment



## Conclusions: FEV

- A market compliant with **urban motorised personal mobility** and other specific cases (freight distribution, < 5 t – GVW; Public Transport)
- Conditioned by **use**, with preferences for known paths: actual autonomy and foreseeable SOC, recharging organisation and scheduling (e.g. PT)
- Inductive charging can be a good solution, especially in some conditions
- EV conditioned by flexible use → **PHEV**
- Heavy masses and long distances → traditional and alternative fuels

Contributions by:

Francesco DEFLORIO, Luca CASTELLO , Ivano PINNA

Paola TOMLIN, Ivan FILIDORO

Bruno DALLA CHIARA (resp.), associate professor, ph.d. eng.

POLITECNICO DI TORINO

Department DIATI - Transport Engineering

corso Duca degli Abruzzi, 24

10129 Torino - Italy - Europe

[bruno.dallachiara@polito.it](mailto:bruno.dallachiara@polito.it)

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Dalla Chiara B., *Range of competitiveness of road FEV: mobility of passengers and freight transport analysis, performances and possible solutions*, Session “The development of electric mobility in Italy: plan and government incentives, the most advanced experiences and new trends in supply”, Green Cars Forum, Lingotto - Torino (I), Politecnico di Torino - *Transport Engineering working group*, 26.09.2013